PATENT SPECIFICATION

DRAWINGS ATTACHED

1,091,101

Date of Application and filing Complete Specification: Nov. 2, 1964.
No. 44642/64.
Application made in United States of America (No. 321246) on Nov. 4, 1963.
Application made in United States of America (No. 402480) on Oct. 8, 1964.
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Index at acceptance: —C7 X1; C7 D(8M, 60, A1, A3)

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ERRATA

SPECIFICATION No. 1,091,101

Page 2, line 46, *for* "particable" *read* "practicable"
Page 2, line 68, *for* "114" *read* "1/4"
Page 2, line 70, *for* "to" *read* "too"
Page 3, line 43, *after* "as" *insert* "a"
Page 5, line 109, *for* "supported" *read* "supporting"
Page 6, line 8, *for* "medium" *read* "media"
Page 9, line 97, *for* "pr ecautions" *read* "precautions"
Page 11, line 127, *for* "enable" *read* "enables"

THE PATENT OFFICE
18th December 1967

strip.

In the production of merchant products and other substantially finished forms of steel, it is conventional to cast the refined or controlled analysis molten metal into large ingots. These ingots are then transferred to large soaking pits where they are kept for a period of time and are brought to a uniformly high temperature. After a desired "soaking period" the heated ingots are transferred to a slabbing or blooming mill and rolled into slabs, blooms, or billets. These intermediate products often are then inventoried and subsequently reheated for hot rolling and sometimes also cold rolling into strip, bars, or rods, in a sequence of operations usually involving special heating cycles, pickling, annealing, and the like. The output of the secondary rolling procedures desirably is in a form suitable for delivery to the steel consumer.

In more recent developments having limited acceptance in the steel industry, the molten metal is continuously cast into slabs or billets, after degassing, which has an advantage of eliminating ingot pouring, soaking pits, and slabbing or blooming mills, but still involves

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The present invention provides a method of converting iron or steel to a particulate form suitable for subsequent consolidation, which method comprises the steps of refining a molten body of the metal to reduce its content of carbon and/or other impurities, controllably discharging the refined metal while it is retained in a molten condition from the refining step, atomising with high pressure solid flat sheet-like streams of liquid the discharging flow of refined molten metal to form solid metal particles of irregular and angular shape, and reducing the content of said liquid associated with the atomized metal particles. The iron or steel so produced in particulate form may be consolidated under pressure to form a strip.

According to the invention there is also provided apparatus for carrying out the above method; which apparatus comprises means for refining the metal means forming a chamber, means for discharging molten metal from the refining means into said chamber, means for directing high velocity solid flat sheet-like

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COMPLETE SPECIFICATION

Production of Powder, Strip and other Metal Products from Refined Molten Metal

I, MAURICE DONALD AYRES, a citizen of the United States of America, of 121 Woodside Drive, Greenwich, Connecticut, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a process and apparatus for the conversion of iron or steel to a particulate form suitable for subsequent consolidation, and also to a process and apparatus for the production of metal strip.

In the production of merchant products and other substantially finished forms of steel, it is conventional to cast the refined or controlled analysis molten metal into large ingots. These ingots are then transferred to large soaking pits where they are kept for a period of time and are brought to a uniformly high temperature. After a desired "soaking period" the heated ingots are transferred to a slabbing or blooming mill and rolled into slabs, blooms, or billets. These intermediate products often are then inventoried and subsequently reheated for hot rolling and sometimes also cold rolling into strip, bars, or rods, in a sequence of operations usually involving special heating cycles, pickling, annealing, and the like. The output of the secondary rolling procedures desirably is in a form suitable for delivery to the steel consumer.

In more recent developments having limited acceptance in the steel industry, the molten metal is continuously cast into slabs or billets, after degassing, which has an advantage of eliminating ingot pouring, soaking pits, and slabbing or blooming mills, but still involves all of the procedural steps and equipment of the merchant or finishing mill, for converting the slabs and billets into final end products.

In either the conventional processing or in the continuous casting system, each step of the overall process is of a character to require huge installations of plant and equipment and large capital investments. For example, economical installations for strip production typically must have a capacity of at least 300,000 tons annually (and usually of 500,000 tons), and the capital and other requirements for such installations tend to limit participation in the industry to a relatively few well-financed companies at a relatively limited number of geographical locations.

The present invention provides a method of converting iron or steel to a particulate form suitable for subsequent consolidation, which method comprises the steps of refining a molten body of the metal to reduce its content of carbon and/or other impurities, controllably discharging the refined metal while it is retained in a molten condition from the refining step, atomising with high pressure solid flat sheet-like streams of liquid the discharging flow of refined molten metal to form solid metal particles of irregular and angular shape, and reducing the content of said liquid associated with the atomized metal particles. The iron or steel so produced in particulate form may be consolidated under pressure to form a strip.

According to the invention there is also provided apparatus for carrying out the above method; which apparatus comprises means for refining the metal means forming a chamber, means for discharging molten metal from the refining means into said chamber, means for directing high velocity solid flat sheet-like

streams of quenching liquid into said chamber in intercepting relation to said molten metal such as to cause atomization of said metal, and means for reducing the content of said liquid associated with the atomized metal particles produced. The invention further provides apparatus for the production of metal strip comprising the aforementioned apparatus together with apparatus for consolidating the metal particles under pressure to form a strip.

The invention is hereinafter more particularly described by way of example only with reference to the accompanying drawings in which:

Fig. 1*a* is a simplified, schematic representation of a process according to the invention for the production of iron or steel in particulate form;

Fig. 1*b* is a similarly simplified, schematic representation of the additional steps for conversion of the metal particles to metal strip;

Fig. 2 is a fragmentary cross-sectional view of an alternative embodiment of atomizing chamber;

Fig. 3 is a fragmentary cross-sectional view taken generally along line 3—3 of Fig. 2;

Fig. 4 is a fragmentary cross-sectional view of a part of an alternative embodiment of apparatus for consolidating the metal particles under pressure to form a strip;

Fig. 5 is a fragmentary cross-sectional view taken generally along line 5—5 of Fig. 4.

Referring now to the drawing, the reference numeral 10 designates a body of molten metal, which is being refined or adjusted as to analysis in a suitable vessel 11. The vessel 11 may be any suitable facility for treating a molten body 10, and typically the vessel will be an open hearth furnace, an electric furnace, an L-D convertor, or the like suitable for refining steel. In the processing of steel, for which this invention is particularly useful, the vessel 11 performs a refining function, preferably to produce a molten iron of the highest particable purity even though it may be necessary or desirable, later in the process, to reintroduce carbon or other alloying agents.

At appropriate times, the refined and/or controlled analysis molten metal 10 is discharged from the vessel 11, typically into a suitable ladle 12, by means of which the molten metal is conveyed to and controllably discharged into an atomizing vessel designated generally by the reference numeral 13. In the system illustrated in Figure 1*a*, the vessel 13 includes an upper housing section, forming an atomizing chamber 15, and a lower housing section 16, forming a collection or receiving chamber. In the top wall of the upper housing section is mounted in receiving crucible 17, provided in its bottom area with one or more (advantageously a plurality) discharge openings 18 for directing one or more small, discrete streams of the molten metal into the atomizing chamber 15. Desirably, the openings 18 are of about 114 inch diameter, and a diameter in excess of abou/ 1/2 inch probably would be to large for an atomizing chamber of typical proportions. A pair of water discharge nozzles 19 are disposed in suitable array within the atomizing chamber and are arranged to direct high pressure (e.g., upwards of 400 psi) streams of atomizing water inward and downward, toward and into intercepting relation with the metal stream discharged from the receiving crucible 17.

Advantageously, the relationship of the molten metal stream to the atomizing water jets is such that the jets forcibly disperse and quickly quench the molten metal and thereby produce predominantly sharp and irregular powder particles, rather than spherical particles. In this respect, because of surface tensions and other influencing factors, the atomized molten metal has a tendency to form substantially spherical powder particles which are less desirable for subsequent compacting into metal products because of the inability of spherical particles to pack closely and to interlock with adjacent particles. The more desirable irregular particles may be achieved by utilizing advantageous forms of quenching streams, issued at sufficiently high water jet velocity, and discharging the molten metal from the receiving crucible in sufficiently small individual streams.

The atomized powder particles may be produced in predominantly irregular form capable of efficient interlocking by so directing the water and metal stream as to prevent substantial contact between the issuing metal streams or metal droplets and small droplets or bubbles of water. This is accomplished by so designing and constructing the water discharge nozzles 19 as to cause them to issue streams of quenching water in the form of solid sheets, rather than in the form of sprays comprised of many individual streams or droplets. To this end, it is advantageous to utilize a nozzle having an elongate discharge slot of, for example, about 1/2 inch in length and 1/32 inch in thickness. This nozzle 19, as shown in more detail in Fig. 3, is advantageously adapted, when operated under appropriately high pressure (typically about 500 psi) to issue a fan-shaped solid sheet of water, as indicated, at 70 in Fig. 3. In an advantageous installation, the solid sheet of water will fan out to a width of about 6 inches and a thickness of about 1/8 inch, at a distance of about 12 inches from the nozzle.

A cooperating pair or pairs of water discharge nozzles 19 advantageously are so arranged that their downwardly and inwardly directed sheet-like streams of water intersect

to form a V-shaped trough, with the apex of the trough being located directly below the molten metal discharge opening 18, such that the discharging streams or droplets of molten metal drop generally symmetrically into the trough.

At the point at which the water streams 70 converge and intercept the descending body of molten metal, there is a substantial tendency for the water to bubble and froth, due in some degree simply to the force of the converging streams and in some degree to the effect of the molten metal being intercepted by the water. It has been found that the formation of bubbles and froth at this point is significantly detrimental to the formation of proper powder particles, because of undesirable steam generation and for other reasons. Thus, the atomizing installation preferably has, in addition to nozzles adapted to issue solid sheets of quenching water, an arrangement in which the nozzles are disposed at a sufficiently small angle to the vertical effectively to prevent bubbling and frothing at the confluence of the water and metal streams. In an actual operating installation, a disposition of each nozzle 19 at an angle of 26° to the vertical was found to produce particularly satisfactory results as regards the formation of predominantly irregular and sharply angular powder particles. With the nozzles 19 disposed at such a small angle, the issuing water streams tend to join smoothly and descend as a single stream into the lower section of the housing.

The atomized particles of refined metal drop into the collecting chamber formed by the lower housing section 16 and are collected in the contained body of cooling water designated by the numeral 20. The powder particles are periodically (or continuously, if desired) removed from the collecting chamber by suitable means such as pump 21 which pumps away the cooling water along with entrained powder particles.

For certain processes, and particularly for the production of high quality iron or steel bars and strip, it is desirable to effect vacuum degassing of the molten metal, and this is accomplished by placing the atomizing chamber 15 under an appropriate vacuum, as by means of a vacuum pump 22. The application of a vacuum to the atomizing chamber 15 is advantageous in a number of respects. First, the exposure of the molten metal streams to the evacuated atomizing chamber causes the streams to literally burst apart, making it easier for occluded gases to be released from the metal. Second, the reduced ambient pressure within the chamber establishes a greater pressure differential relative to the vapor pressures of the gases to promote their release from the molten metal. Partial evacuation of the chamber 15 also significantly improves the efficiency of the atomizing operation by enabling increased areas of the metal to be initially contacted by the high pressure water jets and by causing the molten metal to be drawn through the opening 18 at a greater velocity and rate of flow than would be realized under corresponding conditions with gravity flow alone.

In addition to the evacuation of the atomizing chamber 15, or in place thereof, it is desirable to introduce a controlled atmosphere into the vicinity of the atomized metal particles. In a typical installation, it will be desirable to introduce into the atomizing chamber an inert gas, such as argon, for example, so that the particles are enveloped in a controlled, inert ambient to prevent oxidation or nitrogen pick-up. Naturally, if the atomizing chamber is being maintained in an evacuated condition, the rate of flow of the controlled atmosphere in the chamber will be relatively lower, so as not to entirely balance the effect of the evacuating pump 22. For this purpose, suitable regulating valve means 23 may be provided in the inlet pipe 24 for the controlled atmosphere.

In some instances, and particularly where vacuum degassing of the molten metal is practised, it may be desirable and advantageous to introduce a reducing ambient atmosphere into the atomizing chamber. In such a case, hydrogen gas may be controllably introduced to combine with and neutralize the oxygen released during degassification of the molten metal.

In an advantageous alternative form of atomizing chamber, shown in Figs. 2 and 3, partial evacuation of the upper housing section 71 is effected through the action of the high pressure water streams 70 passing through an orifice 72 in a separator plate or diaphragm 73 which divides the top and bottom sections of the atomizer housing. The converging jets are arranged to meet in the region of the orifice 72, which is of a size and shape to closely accommodate the well-defined water streams.

As indicated in Fig. 1*a*, the cooling water and the iron powder particles entrained therein are discharged by the pump 21 through a conduit 25 and to a dewatering unit 26, which may be a conventional settling basin, filter, or centrifuge. Advantageously, the entrained particles are first passed through an apparatus, such as a separator 27, by means of which low density impurities, such as slag, furnace refractories, and the like, are removed from the higher density metal powder and discharged through an outlet 28.

The dewatered metal powder, which is still, of course, very wet (e.g., 1 percent to perhaps as high as 15 to 20 percent water content) and has a viscous consistency, somewhat like mud, is directed through a conduit 29 or otherwise to a drying and screening chamber 30, in which the powder is heated

to a temperature in the region of 300° F. or over to effect water evaporation.

Advantageously, the water supplied to the system, for atomizing, cooling, and transporting of the iron powder, has suitable additives or treatments to reduce its gas content (principally oxygen and nitrogen). The water thus serves as a temporary protective ambient to prevent oxidation or nitriding of the powder during atomization and during the period it is submerged.

The iron powder introduced into the drying and screening chamber may be exposed to a controlled, inert ambient, typically nitrogen or argon gas, for example, and maintained in this controlled ambient until formation of a substantially finished sheet, strip, or bar, and its emergence from the process at a temperature below that at which oxidation readily occurs. Thus, referring again to Fig. 1*a*, an inert ambient atmosphere such as nitrogen is introduced into the drying and screening chamber 30 through a suitable conduit 31, so that the iron powder is exposed to the atmosphere during the drying process.

As the powder becomes dry, it is passed over suitable screening means (not specifically shown). In some cases, it may be desirable to classify the powder into various size ranges. However, it is usually more desirable to simply screen the particles to pass all those particles smaller than a given size and reject all those particles of greater size. Advantageously, all particles capable of passing through a 40 mesh screen are accepted as a group, and all larger particles are discharged for rework or discarding. It is desirable to work with intermixed particles of various sizes, since the finer particles pack in between the larger particles and facilitate the compacting of the powder particles into a dense, coherent strip of metal.

The dried metal powder particles pass through the screening chamber 30 and are conveyed, advantageously by gas entrainment, through a conduit 32 to temporary holding bins 33, the latter being supplied with an inert atmosphere, such as nitrogen, as through an inlet conduit 34. The temporary holding bins 33 function to absorb temporary fluctuations in the rate of powder making and the rate of subsequent strip formation, as will be understood.

Associated with outlet 35 of a holding bin is a blending chamber 36, in which the primary metal powder particles may be mixed and blended with desired additives, such as detergents, activators, lubricants, binders, or, in appropriate cases, other metal powders or alloying agents. The additives typically may be introduced through an inlet facility 37. Also, reducing atmospheres may be added which will become effective when the powder is later preheated for compacting.

The blending operation is of particular significance because of the advantageous controls provided over the final metal composition, as well as the ability to promote or facilitate certain of the subsequent operations. For example, the addition of appropriate detergents and activators can significantly reduce the times and temperatures required for subsequent heating and/or sintering operations. Further, the detergents and activators, as well as various desirable lubricants and binders, can greatly facilitate the operation of compacting the powder to form a green strip. Of perhaps even greater importance, however, the blending stage permits alloying powders to be mixed with the otherwise high purity metals to achieve a variety of advantageous effects, including the formation of alloys otherwise impossible or impractical to produce.

By way of example, in the production of controlled analysis steel strip the steel first would be refined to iron of the highest practicable purity (particularly as regards carbon content), advantageously to a carbon content of 0.075 percent or less (0.05 percent or less is preferred), so that the basic powder would be as soft as possible for proper subsequent compacting into strip form. At the blending stage, desirable percentages of carbon in various forms or high carbon steel powder may be blended with low carbon iron powder, so that the desired average amount of carbon is present in the final steel strip material. In this respect, while the formation of a metal strip directly from a higher carbon content steel powder would present substantial difficulties, because of hardness of the powder, such difficulties are effectively avoided by blending of low carbon iron or steel and high carbon steel powders to achieve a desired average carbon content in the final strip.

Another particularly advantageous blending procedure which may be followed in the process of the invention is the alloying with iron or steel of relatively high percentages of copper, which can result in significantly increased tensile strength and fatigue endurance of the final product, as well as substantial improvements in its corrosion resistance. By conventional steel making practices, it has not been practicable to utilize copper as an alloying constituent in percentages greater than 0.5 percent, at least without introducing other complicating alloy constituents, because of a tendency of the copper to separate out upon heating of the steel. By contrast, virtually any percentage of copper may be added to the metal in the aforementioned blending step (or in a subsequent infiltration procedure to be described), and true alloy characteristics are realized in the final material.

As may be appreciated from the foregoing, the blending stage offers an opportunity for the convenient preparation of an extremely

wide variety of alloy combinations, enabling an extraordinarily wide range of end products to be produced. Further, the blending of various compositions may be carried out efficiently on a small quantity basis, so that the metal products may economically be prepared specially for particular end uses.

The metal powder can be compacted directly by being controllably fed to the compacting rollers 39, but the use of a preheating apparatus 38 will provide for increased production rates and for desirable operating flexibility. Precise feed control is important in order to achieve a uniform rate of feed toward the compacting rollers 39 and to ensure that the rate is uniform across the entire width of the compacting rollers. Where iron or steel making powder blends are employed in the procedure, the feed control facility (not specifically illustrated) may include appropriate magnetic pump or roller means, for example.

In the preheating chamber 38, the powder particles are heated to a point at which the particles will tend to soften and plasticize, although the temperature should be maintained below that at which the powder mass will become too sticky to process. With a steel making blend of particles, an advantageous preheating temperature is in the region of 1000° F., or over. Experience indicates that the maximum temperature possible is advantageous, but this maximum temperature will vary with different metal or alloys and the methods used.

Advantageously, heat imparted to the powder particles during the drying stage is utilized to assist preheating, where practicable. This is accomplished by delivering the newly dried powder promptly to the preheat stage while maintaining the powder conveying and holding facilities insulated against rapid heat loss.

An advantageous form of preheating and feeding system is illustrated in Figs. 4 and 5, which provides for a high rate of feed while ensuring uniform distribution as well as uniform heating of the powder. The equipment includes a supply chamber 74 in which the powder is given a first stage preheat to as high as about 900° F. The partially preheated powder is then directed through a plurality of spaced distributing tubes 75 which, collectively, form an effectively continuous discharge outlet immediately above the nip of the compacting rollers 39.

The distributing tubes 75 are provided with heater units 77 which impart a second stage preheat to the powder, raising it (in the case of iron or steel making blend) to its final preheat temperature of 950° F. or higher. The preferred range of allowed preheat temperatures is 950° to 1200° F. The distributing tubes, which may be on the order of 1 inch in diameter or less, provide for closely and individually controlled and uniformly effective heating of the powder.

As the powder increases in temperature, entrapped gases expand and must be removed. Accordingly, the system advantageously includes evacuating tubes 78 positioned concentrically within the distributing tubes. They are arranged to efficiently remove air or gases displaced from the powder in the course of feeding, preheating, and compaction.

At the preheat temperatures used in the process, reducing gases previously added to the powder become effective in reducing oxides that may be present. Thus, the powder preheating operation serves not only to soften the powder for more advantageous compacting, but eliminates the need for annealing and oxide reduction operations normally performed in conventional powder production procedures.

Control of the flow of iron or steel powder through the distributing tubes 75 may advantageously be effected through the use of means such as magnetic coil means (not shown) around the tubes. By establishing a downwardly travelling magnetic field, the powder will be, in effect, "pumped" downward. Magnetic means also may be used as valves to effect individual control over the downward flow of powder. Any tendency of the hot powder to stick to the tubes can be reduced by the application of vibrators 79.

The preheated powder particles are compacted by the rollers 39 to a density in the range of 70 to 95 percent that of solid metal strip, and advantageously this is accomplished using compacting rollers having a diameter greatly in excess of the compacted strip thickness (for example on the order of 100 to 300 times the thickness of the initially compacted strip). The product emerging from the first stage of the compacting rollers 39 is referred to as a green strip. It is reasonably integrated and is self-supported but is still quite weak relative to finished metal strip.

Following initial compaction, the green strip is diverted about a guide roller 41 and directed into an elongate heating chamber 42, in which the green strip is heated to a higher temperature, in the range of 1600° F. to 2200° F. The green strip, which may be partially sintered within the heating chamber 42 where desired, is in any event in a desirably heated condition for further compacting, upon its emergence, by means of final stage compacting rollers 43. The rollers 43 serve to compact the heated strip to substantially 100 percent density.

The strip passing through the heating chamber 42, being in a porous condition and at high temperature, is ideally receptive to a variety of gas reaction treatments, such as carburizing, decarburizing, deoxidation, nitriding, chromizing, nickelizing, etc. These

reaction treatments may be advantageously carried out by introducing appropriate gases into the heating chamber or into selected, divided regions of the heating chamber. In this connection, the chamber may be made as long as is necessary and desirable to effect the necessary heating of the strip and its exposure to the reaction medium. Further, advantage may be taken of the heated, porous condition of the green strip within the heating chamber to cause the strip to be infiltrated with a lower melting point metal. Iron or steel strip, for example, may be readily infiltrated with molten copper, such that the product emerging from the heating chamber is a substantially solid material having special properties. Various additives from the blending stage also bring about advantageous effects. Detergents and activators promote sintering or hot compacting, and compounds such as dissociable hydrides release protective or treating gases in the immediate vicinity of the particles.

In the production of iron or steel strip it is contemplated that the densified strip, indicated by the reference numeral 44 in Fig. 1*b*, will be reduced to a substantially finished size or thickness, and one or more hot roll reduction stages 45, 46 advantageously are provided for this purpose, located immediately following the final stage compacting rollers 43, to receive the densified metal while it still retains the heat of the chamber 42. In this connection, the hot-reduced form of a steel or iron strip or bar, designated by the numeral 47 in Fig. 1*b*, may readily fall well within the size ranges conventionally achievable only by cold reduction processes. Thus, in the manufacture of iron and steel strip, following conventional procedures, the practical lower limit of hot-rolled reductions is to a strip thickness of 0.060 inch, and even this lower range is very difficult to achieve. With the procedure described, however, since the thickness of the fully densified strip 44 may be readily controlled at the first compacting stage, the hot reduction may be carried out to minimum strip thicknesses of the order of 0.010 inch without difficulty. Similar advantages are realizable, of course, in the manufacture of substantially finished bars and rods.

The iron or steel powder may be maintained under an inert ambient from the time of its delivery as dried powder to the holding bin 33 to the time of its emergence as a substantially finished product at a temperature below that at which oxidation will readily occur. To this end, it is appropriate to maintain the strip wholly enclosed in a suitable chamber 48 (or series of chambers) which, in effect at least, embraces the strip from the point of its initial formation to the point of its emergence at a relatively low temperature. The chamber 48 is supplied, as through a conduit 49, with a suitable inert atmosphere, such as nitrogen or argon. In this connection, it may be desirable to embrace the strip with a series of individual chambers, rather than a single large chamber as schematically illustrated in Fig. 1b, to achieve various practical conveniences and to minimize requirements of the gas forming the controlled ambient. Further, while nitrogen is a desirable gas for many stages of the strip forming process, it tends to react with iron or steel at higher temperatures, and other gases, such as argon or prepared atmospheres, may be desired for protecting or treating the strip during its passage through the heating chamber 42.

The strip 44 may be protected from oxidation as it travels from the furnace 42 to the cooling sprays 50 by flame curtains, which are reducing. However, it may be desirable in some cases to impart a controlled oxide coating on the strip surface.

Prior to the emergence of the substantially finished strip from its protective ambient, the strip may advantageously be subjected to cooling sprays 50, which serve to reduce the strip temperature to a range of about 300° F. to 400° F. At this temperature, there is very little tendency for iron or steel strip to oxidize.

The cool, substantially finished product is typically directed to a rolling stage 51, for cold reduction, for temper rolling, or for desired surface characteristics. Thereafter, the finished product is directed to a flying shear 52, for example, for cutting into sheets, finite bars, etc., or to a coiler, indicated at 53, for coiling into longer, continuous lengths. Typically, two coilers would be employed to accommodate uninterrupted operation.

In the event that the production of powder exceeds the output of the product-forming end of the continuous process, or where otherwise desirable and expeditious, some of the powder discharged from the drying and screening chamber 30 may be diverted out of the system and bagged or otherwise stored for subsequent use. To this end, the system may include an auxiliary conduit 54, control valve means 55, and a bagging or other storage installation, schematically indicated at 56. Advantageously, the stored or bagged powder is maintained under a controlled ambient for prevention of oxidation. This is usually done by inserting moisture absorbing material such as packages of silica gel.

In some instances it may be desirable or advantageous to produce quantities of powder as an "end product" of a particular installation, for resale to customers or otherwise for subsequent use in various ways. In such cases the dewatered or dried powder is advantageously subjected to a predetermined annealing step prior to packaging, so that the powdered end product has desirable softness to accommodate subsequent compaction of the

powder into metal forms in conventional ways. Typically, the annealing step can be carried out in a controlled atmosphere, but it is possible and practicable, and in many cases desirable and advantageous, to combine annealing with chemical treatment. By way of example, where particularly low carbon content is sought, the anneal may be carried out in a wet atmosphere to bring about carbon-reduction reactions. The metal, being in powder form, presents to the reactive gas a large surface area which facilitates the desired chemical interaction. For some applications it may even be desirable to form a controlled oxide coating on the iron powder, in which case the anneal may be carried out all or in part in an oxidizing atmosphere.

In the manufacture of iron powder, the annealing step may be carried out by heating the powder to a temperature on the general order of 1100° F. to 1350° F.

Annealing is of particular significance because the atomization procedures inherently tend to result in hardened powder particles, which without treatment are less suitable for compaction than may be desired, particularly with respect to batch compacting operations utilizing platen press equipment. The powder, in addition to having a desired, controlled analysis and an advantageous particle shape, by reason of refining and controlled atomization of the molten metal, has, after annealing, the softness more characteristic of costly electrolytic and carbonyl iron powders. In addition, powder resulting from the process may have special desired characteristics imparted by means of a reactive annealing operation. For example the annealing treatment can be arranged to produce particles of electrolytic grade having at least 99% iron content, a carbon content of 0.02% or less, and an oxide content of 0.4% or less measured by hydrogen weight loss.

In a typical operation according to the invention in which the starting raw material was scrap steel, and the analysis of non-ferrous elements in the starting material was somewhat as follows:

	Percent
Carbon	0.18
Manganese	0.57
Sulfur	0.032
Silicon	0.04
Chromium	0.01
Molybdenum	0.01
Copper	0.03
Phosphorus	0.015

The starting material of the above analysis was refined in a vessel 11 to a condition of high purity such that the powder product formed with the refined steel had an approximate analysis, after annealing, as follows:

	Percent
Carbon	0.026
Manganese	0.120
Sulfur	0.027
Silicon	0.050
Chromium	0.000
Molybdenum	0.010
Copper	0.030
Phosphorus	0.010
Oxygen	0.410
Nitrogen	0.010
Acid Insolubles	0.280
Iron	99.18
Sieve Analysis (through 80 mesh sieve)	90.10

The resulting low carbon powder is useful and indeed especially desirable in its subsequently produced strip form for small electrical motor manufacture, because of the particularly good magnetic properties of the strip, coupled with its low cost. Even greater advantages are realized for this purpose when a controlled surface oxide coating is imparted to the strip.

By using selected quality raw materials, such as pig iron of preferred analysis, powder of even greater purity can be produced without difficulty. A typical approximate analysis of such a higher purity powder is as follows:

	Percent
Carbon	0.015
Manganese	0.008
Sulfur	0.020
Silicon	0.038
Chromium	0.000
Molybdenum	0.001
Copper	0.025
Phosphorus	0.010
Oxygen	0.320
Nitrogen	0.010
Acid Insolubles	0.025
Iron	99.30
Sieve Analysis (through 80 mesh sieve)	98.00

Low carbon powder of the foregoing typical analysis may be alloyed or otherwise modified by powder additions at the blending stage, such that entirely new metal and metal product fields may be opened up. Similarly existing types of metal products, heretofore prohibitively costly or otherwise economically disadvantageous, may be made available on a practical basis utilizing the procedures of the invention. For instance, stainless steel products such as strip, bars, or rods can be advantageously produced by this method because of the reduced number of operations necessary. Stainless steel powder of the following analysis has been produced:

	Percent
Carbon	0.09
Chromium	18.15
Nickel	9.08
Manganese	0.47
Silicon	0.91
Iron	Balance

This powder made quality stainless steel strip when the heating operation was carried out above 2000° F. and in a very dry hydrogen atmosphere.

The process may be performed without interruption from the molten metal stage to the substantially finished product stage with close control over analysis of the molten and blended metals and over the composition of the final strip. In the case of steel products, significantly increased quality may be realized through the elimination of such defects as pipe, blow holes, segregation, cracks, and non-metallic inclusions, formed when steel is conventionally cast into ingots, and from the elimination of other defects caused in the many heating, rolling, handling, and other numerous operations conventionally required to produce a substantially finished product.

Iron strip made in accordance with the above-described procedures may be adapted particularly for electrical applications, in the manufacture of laminated cores for small motors, transformers, solenoids, and the like. The manufacture of strip for electrical purposes is a substantial segment of the iron and steel industry, which involves important tonnage requirements of strip. This strip is specified for desirable magnetic properties, in addition to appropriate forming characteristics. The desired forming characteristics typically involve good "punchability" and may also involve uniform gauge, flatness, desired grain and crystallographic structure, softness, resistance to cold welding, etc. Iron strip manufactured in accordance with the process of the invention is particularly adaptable to electrical end uses because, among other reasons, of the ability under the new process to control both the nature and extent of impurities and to control the size of grain. Probably the most important factors affecting the magnetic properties of iron powder and strip (as well as the ability of iron powder to compact into strip) are the carbon and nitrogen contents of the metal. Both nitrogen and carbon can be controlled with precision in the process above described and reduced to very low levels without incurring extraordinary manufacturing expenses. Moreover, such of these impurities as are present are largely in the form of fine boundary precipitates which do not adversely affect the magnetic properties as do dissolved impurities; rather they tend to impart desirable properties to the strip, as by improving punchability and lowering eddy current losses. The advantages of carbon and nitrogen control, of course, may be realized in all end uses of the powder. Ability to compact the powder into strip or other solid forms to maximum density with minimum pressure is one of the most important resulting characteristics. The advantages of particular significance in connection with electrical strip are that desirable magnetic and other characteristics may be realized through the control of both the amount and the nature of carbon and nitrogen in the manufacture of powder and the strip.

Nitrogen content can be reduced and controlled by a variety of procedural steps, many or all of which advantageously would be varied in a particular operation. Thus, in the refining stage, nitrogen content is removed by flushing and by the addition to the molten bath of iron ore or iron oxides, to bring about a so-called carbon boil which accompanies reduction of the ores and oxides. Regardless of the utilization of the carbon boil procedure, the molten metal, during both its containment in the refining vessel and its atomization, can be protected from the nitrogen content of the atmosphere, as by formation of a slag surface layer on the bath in the refining vessel and/or the provision of a suitable inert (e.g., argon gas) atmosphere during refining, pouring, and atomizing. The atomizing medium itself, which is advantageously water, can be desirably treated to remove as much as possible of the dissolved or contained nitrogen or nitrogen compounds, so that the metal remains protected even after immersion in the quenching liquid. If, after the atomizing step, the powder still analyzes to a higher nitrogen content than desired, a further reduction of nitrogen content may be carried out during an annealing step or during sintering of the powder, powder compact, or porous strip, as by treatment in a hydrogen atmosphere.

Carbon content can be readily controlled first by appropriate selection of metal for the melting and refining procedure and, in conjunction therewith, adding carbon to or removing it from the bath of molten metal during refining, in accordance with well-known procedures. Where appropriate, further reduction in the carbon content can be brought about in the atomizing stage, as by atomizing the powder in an evacuated atmosphere to reduce the carbon monoxide content of the metal. Thereafter, additional carbon can be removed easily and controllably from the powder, compact or strip during subsequent annealing or sintering operations.

In a typical process one may without difficulty produce electrical strip having a carbon content of less than 0.02 percent and a nitrogen content of less than 0.01 percent. These levels are eminently suitable for typical electrical strip applications. In general, it would appear that the combined carbon and nitrogen

content of the iron should not significantly exceed a total of 0.04 percent and experience demonstrates that these impurities are easily maintained well below this indicated upper limit.

In instances where electrical strip of good electrical characteristics is desired, collateral difficulties may arise with respect to the punchability of the strip, because of the relative softness of the finished, high purity strip. In such a case, it may be desirable and advantageous to impart to the surface of the powder particles (but not homogeneously to the entire body of the metal) trace coatings of such impurities as oxides, nitrides, phosphorus or manganese. These surface impurities significantly improve the shear properties of the strip and impart good punching characteristics, but are significantly detrimental to the electrical properties of the finished strip.

Another feature of this process that improves the punchability of laminations is that the strip can be produced at less than 100 percent density. Controlled compacting and processing of strip can produce soft annealed strip containing many small pores or voids. The presence of these improve the shearing action of the punch as it passes through the strip.

Trace coatings of impurities on the powder particles and small voids in the strip either individually or together make possible the production of strip which can be given a final heat treatment and thereafter punched and used. The normal practice is to punch the lamination from a strip, heat treat by a less effective method, and then use. Conventional strip that has received its final heat treatment cannot be punched satisfactorily.

It may also be desirable to impart a controlled oxide coating to the surface of the finished electrical strip, to provide a desired measure of electrical insulation between adjacent layers of a laminated stack.

Quite apart from the case of controlling the content of significant impurities, such as carbon and nitrogen, the procedure above described is advantageous in the manufacture of electrical strip because of the substantially simplified procedures for the formation of the strip. Under conventional procedures, for example, the metal is refined in the usual manner and poured into ingots, which are subsequently rolled into slabs. Typically, the slabs are then hot rolled and coiled in continuous hot strip mills and later pickled to remove surface oxides. Thereafter, the hot rolled strip may undergo a plurality of cold reduction steps, each followed by annealing, after which the cold reduced strip is given a final high temperature anneal.

In contrast, the described procedure of the invention enables the metal to be formed initially at a controlled, minimum strip thickness, from which it may be directly hot reduced to a usable thickness. Not only does this avoid significant manufacturing steps, involving substantial time and plant installation, but it also affords desirable control of internal stress and grain formation which have a significant effect upon the electrical properties of the finished product.

In a typical specific procedure for the preparation of electrical strip for routine applications, a desirable raw material would be in the form of a light scrap iron, most advantageously taken from punching operations and electrical lamination plants, but suitably also from other supplies of plain carbon steel scrap. This scrap may be melted in an electric furnace, under conditions substantially excluding contact of the metal with nitrogen, as by melting under an atmosphere of argon or under a slag blanket. Typically, melting and refining of the metal is carried on to the point where the carbon content of the melt is relatively low, advantageously 0.13 percent or less. The refined molten metal is atomized in the manner hereinabove described, with particular care being taken to minimize exposure of the molten metal to nitrogen-containing atmosphere or nitrogen-containing cooling water. Although some slight nitrogen content, as in the form of surface nitrides, may be advantageous, deleterious amounts of dissolved nitrogen will be present unless pr ecautions are taken at this stage to avoid excessive exposure of the molten metal to nitrogen (and also at subsequent stages to avoid exposure of the powder to nitrogen when the powder is at a temperature of around 1350° F. or above).

After atomization, the relatively nitrogen-free powder is dewatered. If desired, the drying operation can be, in effect, an annealing and an extended chemical heat treatment, to reduce the carbon and oxygen contents to relatively low levels of about 0.005 percent carbon and 0.05 percent oxygen. At the other extreme, the dewatering operation may simply lower the water content to about 5 percent moisture, with the chemical heat treatment being carried out in subsequent operations.

The dried powder is screened to remove oversized particles, typically leaving a balance of particles predominantly in the size range of about minus 40 mesh. The screened particles may then be treated by milling, tumbling, blending etc., if desired, to achieve certain characteristics of flowability, compressibility, and apparent density. and the powder at this stage may also be combined with so-called detergents. If particularly high quality electrical strip is being produced, it may be done in two ways: Elements such as silicon or a silicon compound, normally ferro silicon, can be included in the molten metal so that the powder produced is an iron alloy of desired analysis. A typical example

of silicon-iron alloy powder that has been produced is as follows:

	Percent
Carbon	0.13
Manganese	0.33
Sulfur	0.03
Silicon	1.35
Phosphorus	0.01
Nitrogen	0.029
Iron	Balance

In the subsequently produced strip, the carbon was reduced to 0.015 percent and the nitrogen to 0.015 percent. The second way is to add to the iron powder agents calculated to increase the electrical properties of the mix, suitable agents being electrolytic silicon metal powder, ferro silicon, or certain organic silicon compounds, such as silane compounds. It should be particularly noted that additions if utilized may be introduced into the atomized and solidified powder as well as into the original melt.

The dried "electrical" powder, preheated if appropriate, is charged into the rolling stand for compacting and hot rolling generally in the manner previously described. If desired, the compacted and/or partially hot rolled strip may be given a chemical heat treatment, advantageously at a stage at which its density is of the order of 85 to 98 percent of theoretical iron density. The heat treatment is continued as long as necessary to bring the carbon, oxygen, and nitrogen contents down to desired levels. Strip made from iron powder (without silicon or other additions) can acquire a magnetic induction of 15 kilogausses at magnetizing forces as low as 10 RMS ampere turns per inch, with losses of no more than 5.5 watts per pound. This is as compared to conventional non-silicon electrical steel, which requires magnetizing forces as high as 15 RMS ampere turns per inch, with losses as high as 7 watts per pound to reach inductions of 15 kilogausses.

In the chemical heat treatment of the compacted and/or rolled strip, the treating atmosphere advantageously contains considerable water vapor to reduce the carbon content of the strip and is reducing in order to react with oxygen present. Powder or porous strip is so reactive to gases that powder with carbon content of 0.38 percent has been reduced to 0.07 percent in a normal powder anneal and this same powder (0.38 percent carbon) when compacted into a strip and sintered (without annealing of the powder) had a carbon content as low as 0.02 percent.

In a typical procedure, the prepared powder is compacted, then subjected to heating, advantageously in conjunction with a chemical heat treatment. Thereafter, and as part of the continuous procedure, the compacted and treated powder is hot rolled to a thickness equal to or closely approaching the final gauge. In other instances it may be desirable to perform chemical heat treatment in another, separate stage, in which event the prepared powder may be compacted, heated and then hot rolled into coils. Subsequently, the hot rolled coils are given appropriate chemical heat treatments or other treatments and they may then be cold rolled to a final gauge. If cold rolling is involved in the procedure, a subsequent annealing step normally would be performed.

The electrical strip manufactured in accordance with the above-described procedure is especially desirable because significantly improved electrical and mechanical properties are achieved without increase in cost. These properties of the material are realized in the process of the invention because the electrical strip is formed with relatively large grains which are extremely pure internally to impart desirable softness and permeability and desirably high saturation magnetization and low coercive force, but have some interstitial impurities in the form of nitrides, oxides, and other precipitates, initially formed on the surfaces of the powder particles and eventually forming and retentively defining the grain boundaries. The result of this structure is to provide large individual grains of pure iron separated by high resistivity boundaries to limit eddy current losses. The impurity-defined grain boundaries also impart highly desirable shear properties between the individual grains, to provide significantly improved punchability of the strip. This property can also be improved by producing strip with pores which reduces the strip to a density of less than 100 percent. The property of good punchability is of substantial practical importance, since the magnetic structures formed of electrical strip typically are comprised of laminated stacks of punched-out shapes.

The described grain boundary characteristics of the particles and porosity of the strip also are of significance in imparting increased resistivity between the laminated elements and in reducing any tendency of the otherwise relatively soft iron strip sections to cold weld to the punching dies or to adjacent strip sections.

Although electrical strip produced as described may have quantities (e.g., up to about 5 to 6 percent) of silicon added, where particularly high quality electrical properties are sought, it is possible to obtain electrical properties in substantially silicon-free carbon steel strip which are achievable in conventional materials only through the addition of silicon or other similar additives. In addition, the strip has significant collateral advantages of a mechanical nature such as ease of stacking and improved punchability.

The combined properties of the completed strip for electrical applications are advan-

tageous in that the combination of large, highly pure particles surrounded and separated by boundary coatings in the form of relatively trace quantities of nitrides, oxides, and other compounds, as well as containing a desired amount of porosity, simultaneously imparts to the finished strip electrical and mechanical properties which heretofore have been considered relatively mutually exclusive. The large, pure particles result in desirable electrical characteristics of high saturation magnetization, high permeability, low coercive force and accompanying low hysteresis loss. This strip possesses the quality of satisfactory punchability after the final heat treating operation for maximum electrical qualities. This has not previously been found feasible with strip made in the conventional manner.

Interstitial precipitates, in the relatively minor quantities present, and/or the controlled porosity impart very desirable characteristics, both mechanical and electrical, to the strip. Electrically, the precipitates, in the form of nitrides, oxides, and other electrically resistant compounds, serve to limit the flow of current between particles, so that the eddy currents tend to be confined within the individual particles or grains, a condition which significantly reduces eddy current losses.

Mechanically, the interstitial precipitates and pores are advantageous in improving the shear properties of the metal, relative to conventional metals of similarly low impurity content, so that the desired punchability characteristics are realized without subjecting the metal to work hardening or other treatments, which not only add cost but introduce other undesirable side effects such as internal stresses. Good punchability requires low ductility without brittleness, a well defined yield point, and a minimum tendency to weld cold, and all of these conditions are relatively optimized in the material of the present invention by reason of the unusual grain structure of the compacted strip, consisting of large, pure particles with grain boundaries defined by fine trace precipitates of relatively brittle carbon, nitrogen, and oxygen compounds and/or pores in the strip.

In the manufacture of certain other steel products for general applications, as well as for electrical strip, it is especially significant that the intermediate stage of the metal is in the form of low carbon iron or steel powder particles, rather than in the conventional form of ingots at one intermediate stage and slabs, blooms, or billets at another intermediate stage. With the described procedure, the same intermediate material —powder of controlled, desired analysis— may be utilized in the formation of strip, bars, rods, etc., and intermediate handling and storage operation may be reduced to a minimum. The process described also enables the production in commercial quantities of many steel products which heretofore have been unable to be produced, at least otherwise than on a laboratory basis. One important class of steel products which may be produced using the process described is hot-rolled strip in gauges of less than 0.060 and well down into the range conventionally available as the more expensive cold-rolled strips.

The concept of initially preparing iron or steel powder of the highest practicable purity particularly as regards carbon content, to achieve desirable properties for subsequent compaction into green strip, and preparing an alloy blend by alloy powder additions made prior to the compacting operations is of special importance. Thus, even where the blending step simply restores certain of the elements removed during refining, significant practical advantages may be realized by reason of the desirable compacting properties of the soft, pure powder, which serves in effect as a matrix for the alloying powders.

In following the process described, significant economies may be realized and substantial reduction in capital costs for equipment are made possible. Further, it is economically feasible to carry out the process disclosed with low cost, low capacity installations, so that an iron and steel making process may be carried out at a greater number of locations in closer proximity to individual cities or plants to which the output is to be delivered or in proximity to sources of raw materials. In this connection, the described process may be economically carried out with plants of 5,000 to 100,000 ton capacity.

Additional important economic advantages are realized because of significantly higher yields in converting molten metal to finished products, yields of 90 percent and above being contemplated with the process disclosed, as compared to yields in the range of 70 percent for many conventional production procedures. Further, with the process described, it is possible to produce hot-rolled strip gauges which are well below the conventional hot-rolled gauges, to supply substantial markets presently filled only by substantially more expensive cold reduced strip.

In addition to the above-stated and other advantages of an essentially economic nature, the process described affords a wide range of flexibility in the types and quality of the products capable of being produced, through control over the molten metal primary input and through blending and other operations which are possible after the primary molten metal component has been converted to its intermediate, powder stage. This is of particular importance in that it enable the metal product to be specifically tailored to the desired end use, rather than accommodating the end use to the available metals as has been

more common heretofore. Improved product quality is realized not only through close control of the metal refining and analysis adjustment, made possible by the integrated nature of the process, but also by the avoidance of defects otherwise arising through the conventional ingot casting rolling and processing.

WHAT WE CLAIM IS:—

1. A method of converting iron or steel to a particulate form suitable for subsequent consolidation, which method comprises the steps of refining a molten body of the metal to reduce its content of carbon and/or other impurities, controllably discharging the refined metal while it is retained in a molten condition from the refining step, atomising with high pressure solid flat sheet-like streams of liquid the discharging flow of refined molten metal to form solid powder particles of irregular and angular shape, and reducing the content of said liquid associated with the atomized metal particles.

2. A method according to Claim 1, wherein the metal is refined to the highest practicable purity, and alloying elements are added to the refined metal to form a molten alloy.

3. A method according to Claim 1 or Claim 2, wherein the discharging flow of molten metal is exposed to a partially evacuated ambient during the atomising step, whereby degassing of the molten metal and disintegration of the metal into particulate form is promoted.

4. A method according to any of Claims 1, 2 or 3, wherein the discharging flow of molten metal is intercepted and atomised by opposed high pressure streams of quenching liquid directed downward and inward into intercepting relation, the streams being of substantially continuous sheets intersecting in a V.

5. A method according to Claim 4, wherein said sheet-like streams are directed downward at an angle of 26° to the vertical.

6. A method according to any preceding claim wherein the atomising liquid is water, the atomised metal particles are collected in a body of collected water, and are conveyed from the atomising step by entrainment in a flow of the collected water, and the metal particles are separated from impurities of significantly lower density.

7. A method according to any preceding claim, wherein the metal particles are dried in an oxygen free ambient to provide dry particles free of appreciable oxide pick-up.

8. A method according to any preceding claim, wherein the metal particles are annealed in a controlled atmosphere, the method being arranged to produce metal particles of electrolytic grade having at least 99% iron content, a carbon content of 0.02% or less, and an oxide content of 0.4% or less as measured by hydrogen weight loss.

9. A method of converting iron or steel to a particulate form suitable for subsequent consolidation which method is substantially as hereinbefore described with reference to, and as shown, in Fig. 1A or Fig. 1A as modified by Figs. 2 and 3 of the accompanying drawings.

10. A method of producing metal strip comprising the step of converting iron or steel to a particulate form according to any preceding claim, and consolidating the metal particles under pressure to form a strip.

11. A method according to Claim 10, wherein said particles are annealed prior to compression into a fully consolidated strip.

12. A method according to Claim 10 or 11, wherein the particles are roll compacted to form a porous green strip, which porous strip is further compressed to a substantially fully consolidated strip.

13. A method according to Claim 12, wherein the porous green strip is produced by preheating the particles to between 950° F and 1200° F. and compressing the particles to form a partly densified coherent length of metal.

14. A method according to Claim 12 or 13, wherein the porous green strip is heated in a controlled atmosphere.

15. A method according to Claim 14, wherein the green strip is heated to a temperature between 1600° F. and 2200° F.

16. A method according to Claim 14 or 15, wherein the porous strip is exposed to a molten metal of lower melting point during the heating step to effect infiltration of the porous metal by said molten metal.

17. A method according to Claim 14, 15 or 16, wherein the porous strip is hot rolled to a predetermined size and cross-section while the metal retains substantial heat from the heating step.

18. A method according to Claim 17, wherein the hot-rolled metal is cooled, the metal being maintained in a non-oxidising ambient substantially from the time of the liquid content reduction step to a time, following the heating step, when the metal is below the temperature at which oxidation readily occurs.

19. A method according to Claim 17 wherein the heated porous strip is exposed to a reactive gaseous medium to effect chemical treatment while said strip is at an elevated temperature from said heating step and before the strip is fully consolidated.

20. A method according to Claims 14, 15, 16, 17 or 19, wherein the porous strip is exposed to a reactive gaseous medium to effect chemical treatment during said heating step.

21. A method according to Claim 19 or 20 wherein the reactive gaseous medium is chosen to reduce the combined carbon and nitrogen content of the porous strip.

22. A method according to any of Claims

10 to 21, wherein additional ingredients are added to the metal particles before consolidation to form a strip.

23. A method according to Claim 22, wherein the metal is treated subsequent to atomization to impart to the outer surfaces of the powder particles trace coatings of impurities.

24. A method according to Claim 17 or any of Claims 18 to 23 as appendant to Claim 17, wherein the strip is rolled to a gauge of between 0.06 inch and 0.01 inch, and the refining and subsequent steps are so controlled as to provide a strip having a carbon contact of 0.05% or less.

25. A method according to Claim 22, wherein the molten body of metal is refined to an analysis comprising a carbon content of 0.075% or less, and additional carbon is added to the atomized particles before consolidation to form a strip.

26. A method according to any of Claims 10 to 24, wherein the refining and subsequent steps are so controlled as to provide a strip having a combined carbon and nitrogen content of 0.04% or less.

27. A method according to any of Claims 10 to 26, wherein the refining and subsequent steps are so performed and controlled as to provide a strip wherein the impurities are concentrated in the grain boundaries, the strip being particularly useful for electrical uses.

28. A method according to any of Claims 10 to 27, wherein the consolidated strip is further rolled, for cold reduction, temper rolling, or for desired surface characteristics.

29. A method of producing metal strip substantially as hereinbefore described with reference to, and as shown in, Figs. 1A and 1B or Figs. 1A and 1B as modified by any of Figs. 2 to 5 of the accompanying drawings.

30. Apparatus for carrying out the method of Claim 1; which apparatus comprises means for refining the metal, means forming a chamber, means for discharging molten metal from the refining means into said chamber, means for directing high velocity solid flat sheet-like streams of quenching liquid into said chamber in intercepting relation to said molten metal such as to cause atomization of said metal, and means for reducing the content of said liquid associated with the atomized metal particles produced.

31. Apparatus according to Claim 30, wherein said chamber is divided into a substantially closed upper section and a lower section by a separator having an orifice connecting the two chamber sections, molten metal being discharged into the upper section, and the streams of quenching liquid being arranged to intercept and pass through said orifice, the action of the high velocity stream of quenching liquid passing through said orifice being effective to partially evacuate the upper chamber section.

32. Apparatus for converting iron or steel to particulate form suitable for subsequent consolidation, which apparatus is substantially as hereinbefore described with reference to, and as shown in, Figs. 1A or Fig. 1A as modified by Figs. 2 and 3 of the accompany-panying drawings.

33. Apparatus for the production of metal strip comprising apparatus according to Claims 30, 31 or 32, for converting iron or steel to particulate form, and apparatus for consolidating the metal particles under pressure to form a strip.

34. Apparatus according to Claim 33 wherein the consolidation apparatus includes means for feeding metal particles to the nip of a pair of compacting rollers; which feeding means comprise a supply chamber for the powder, a plurality of distributing tubes connected to the supply chamber and arranged in side-by-side relation, the discharge ends of the distributing tubes being arranged in a line to form an effectively continuous sheet-like powder discharge, and means to control the passage of powder through the individual distributing tubes.

35. Apparatus according to Claim 34, wherein means are provided to partially evacuate portions of said distributing tubes to facilitate removal of gas from the powder.

36. Apparatus for the production of metal strip substantially as hereinbefore described with reference to, and as shown in, Figs. 1A and 1B or Figs. 1A and 1B as modified by any of Figs. 2 to 5 of the accompanying drawings.

37. Metal particles produced by a method according to any of Claims 1 to 9 or by apparatus according to any of Claims 30 to 32.

38. Metal strip produced by a method according to any of Claims 10 to 29 or by apparatus according to any of Claims 33 to 36.

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Sheet 1

FIG. 1A

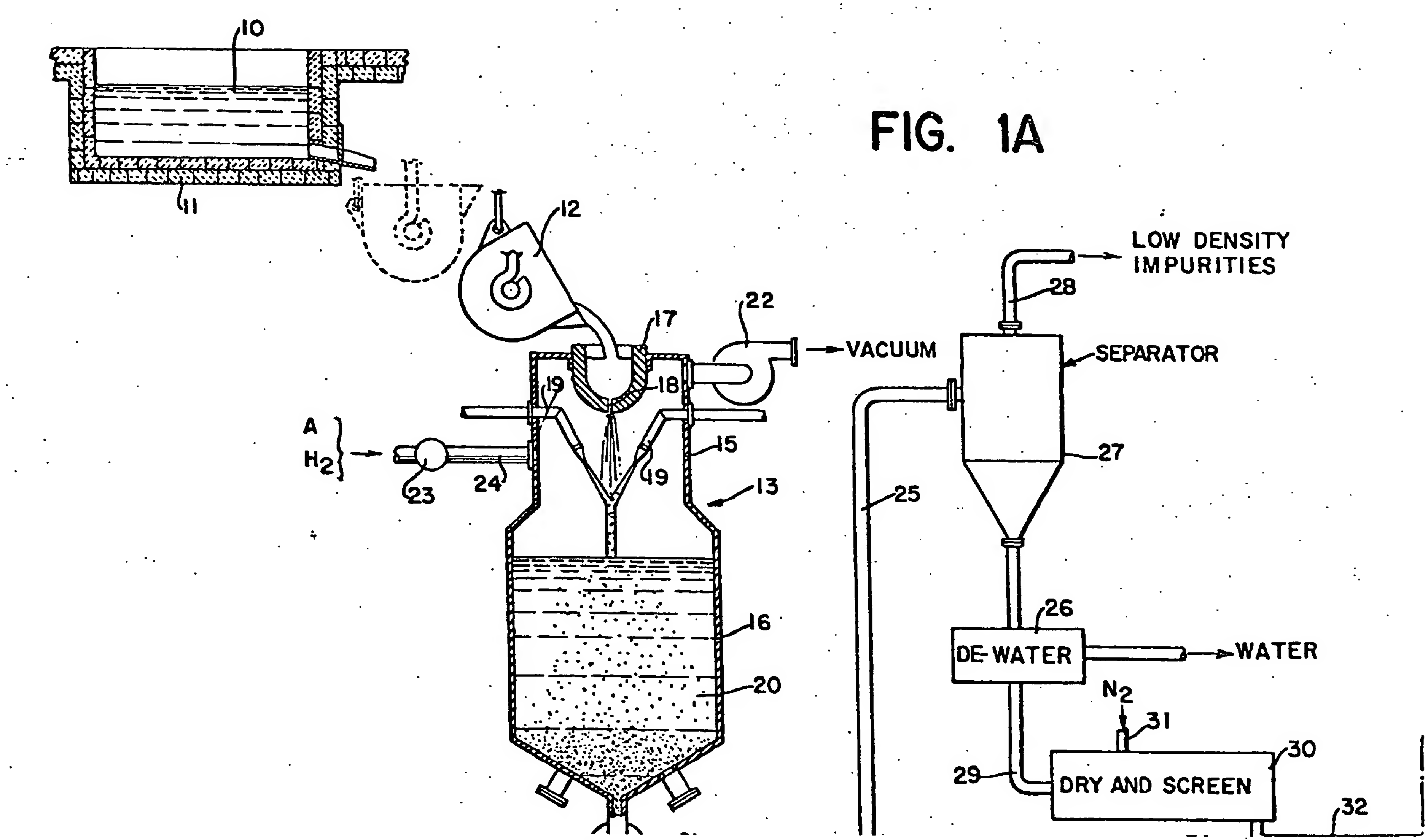

FIG. 1B

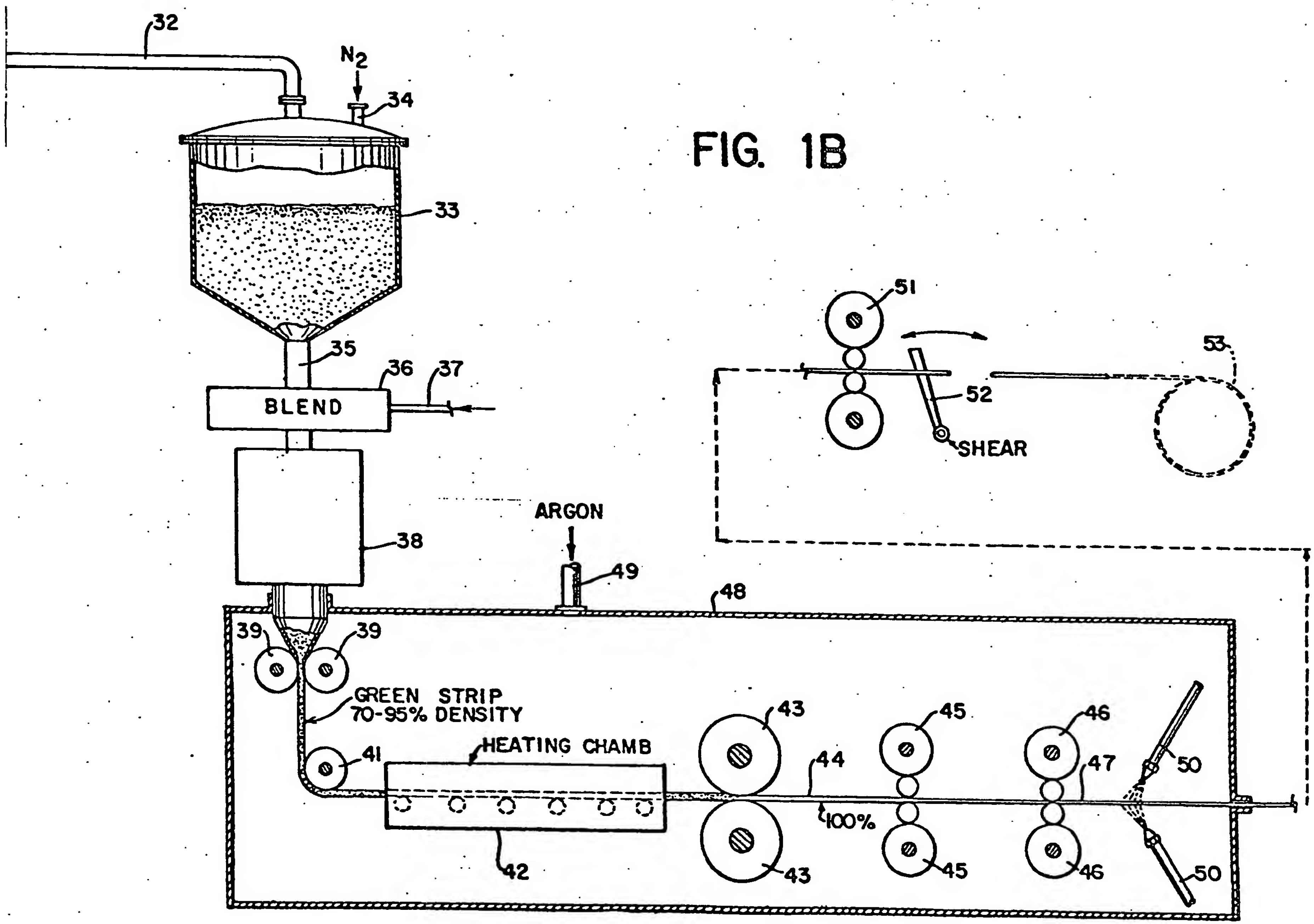
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FIG. 2

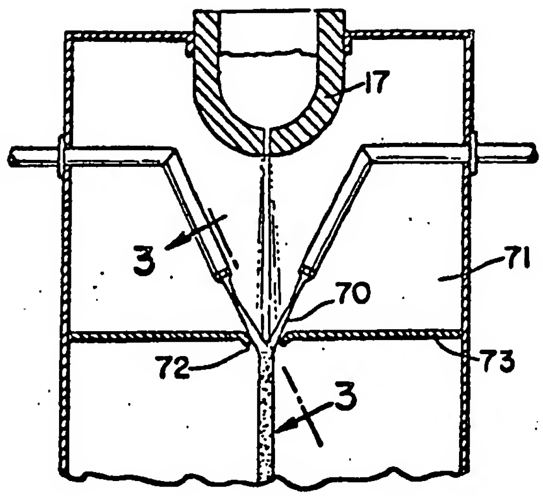
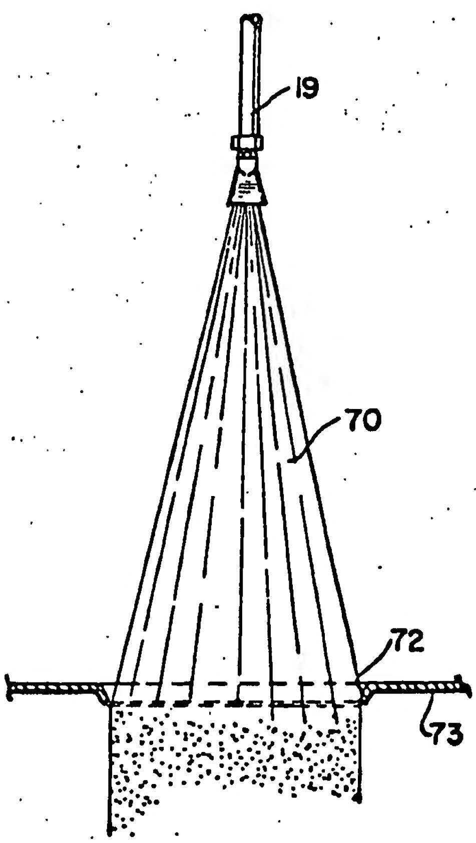
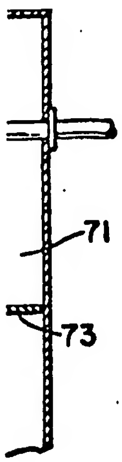


FIG. 3





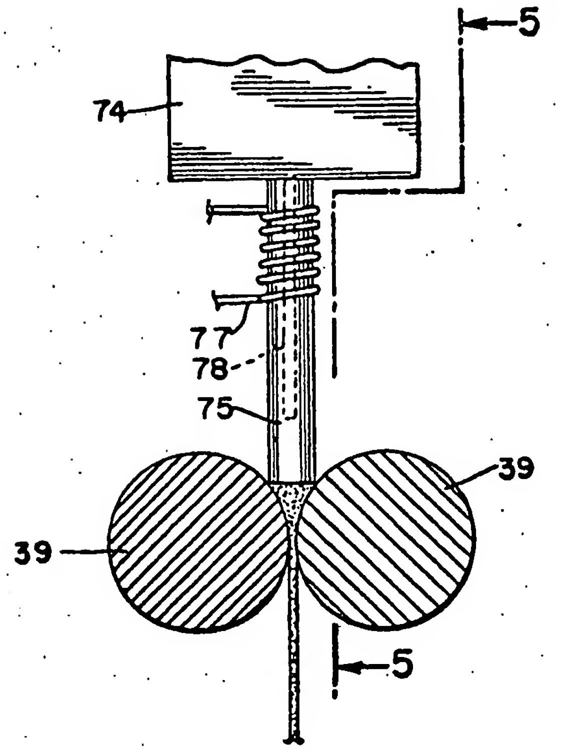


FIG. 4

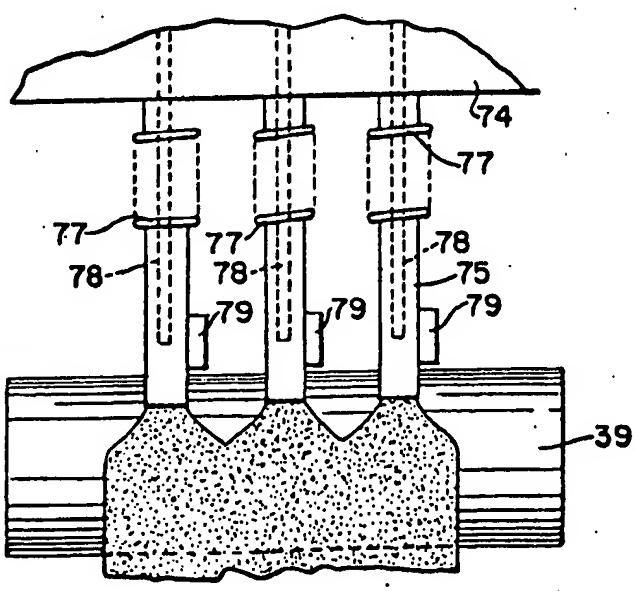


FIG. 5

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